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Process for the continuously operated purification by distillation of the methanol solvent used in the coproduct-free synthesis of propylene oxide, with the methoxypropanols being separated off simultaneously

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The present invention relates to a continuously operated process for the purification by distillation of the methanol used as solvent in the synthesis of propylene oxide by reaction of a hydroperoxide with propylene, with the methoxypropanols and the low boilers and high boilers being separated off simultaneously using a dividing wall column. Preference is given to using a column having two side offtakes. The solvent mixture obtained in the synthesis is separated into a low-boiling fraction, a high-boiling fraction and two intermediate-boiling fractions, with methanol being obtained as one intermediate-boiling fraction from one of the side offtakes and the methoxypropanols being obtained as azeotrope with water as the other intermediate-boiling fraction from the second side offtake. In a preferred embodiment, the dividing wall column can also be in the form of thermally coupled columns.

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In the customary processes of the prior art, propylene oxide can be obtained by reaction of propylene with hydroperoxides in one or more stages.

For example, the multistage process described in WO 00/07965 provides for the reaction to comprise at least the steps (i) to (iii):

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- (i) reaction of the hydroperoxide with propylene to give a product mixture comprising propylene oxide and unreacted hydroperoxide,
 - (ii) separation of the unreacted hydroperoxide from the mixture resulting from step (i),
 - (iii) reaction of the hydroperoxide which has been separated off in step (ii) with propylene.

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Accordingly, the reaction of propylene with the hydroperoxide takes place in at least two steps (i) and (iii), with the hydroperoxide separated off in step (ii) being reused in the reaction.

The reactions in steps (i) and (iii) are carried out in two separate reactors which are preferably configured as fixed-bed reactors. It is advantageous to carry out step (i) under substantially isothermal reaction conditions and step (iii) under adiabatic reaction conditions. It is likewise advantageous for the reaction to be heterogeneously catalyzed.

This reaction sequence is preferably carried out in a solvent and the hydroperoxide used is preferably hydrogen peroxide. The particularly preferred solvent is methanol.

Here, the hydrogen peroxide conversion in step (i) is from about 85% to 90% and that in step (iii) is about 95% based on step (ii). Over both steps, the total hydrogen peroxide conversion is about 99% at a propylene oxide selectivity of about 94-95%.

Owing to the high selectivity of the reaction, this process is also referred to as the coproduct-free synthesis of propylene oxide.

The propylene oxide has to be separated off from a mixture comprising methanol as solvent, water, hydrogen peroxide as hydroperoxide and also by-products. By-products are, for example, the methoxypropanols, viz. 1-methoxy-2-propanol and 2-methoxy-1-propanol, which are formed by reaction of propylene oxide with methanol. Relatively high-boiling substances such as propylene glycols and also relatively low-boiling substances such as acetaldehyde, methyl formate and unreacted propylene are also present in the mixture. The propylene oxide is obtained from this mixture by fractional distillation.

This distillation also gives fractions which comprise methanol and the methoxypropanols as materials of value. These propanol ethers can be used, for example, as solvents in surface coating systems.

The separation processes carried out for recovering these materials of value have hitherto typically been carried out in distillation columns having a side offtake or in columns connected in series. This procedure is costly because it has an increased energy requirement and an increased outlay in terms of apparatus.

It is an object of the present invention to optimize the purification by distillation of the methanol used as solvent in the preferably coproduct-free synthesis of propylene oxide by reaction of a hydroperoxide with propylene, so that the methoxypropanols are simultaneously recovered and the otherwise usual energy requirement is reduced. The

solvent should be obtained in a quality which enables it to be reused for the abovementioned synthesis of propylene oxide.

We have found that this object is achieved by a continuously operated process for the purification by distillation of the methanol used as solvent in the preferably coproduct-free synthesis of propylene oxide by reaction of a hydroperoxide with propylene and also the methoxypropanols formed in a dividing wall column.

The present invention accordingly provides a continuously operated process for the purification by distillation of the methanol used as solvent in the synthesis of propylene oxide by reaction of a hydroperoxide with propylene, with the methoxypropanols and the low boilers and high boilers simultaneously being separated off, wherein the solvent mixture obtained in the synthesis is fractionated in a dividing wall column.

The process of the present invention enables the methanol to be obtained in sufficiently pure form for it to be able to be reused, for example, for the synthesis of propylene oxide. The methoxypropanols, too, are obtained in good purity as an azeotropic mixture with water. Compared to the processes disclosed in the prior art, the novel process of the present invention leads to a reduced outlay in terms of apparatus. Furthermore, the dividing wall column has a particularly low energy consumption and thus offers advantages in terms of the energy requirement over a conventional column or an assembly of conventional columns. This is highly advantageous for industrial use.

According to the present invention, a dividing wall column having two side offtakes is used since it allows the low boilers and high boilers to be separated off and also enables the methanol and the methoxypropanols as azeotrope with water to be separated from one another particularly well.

In a preferred embodiment of the process of the present invention, therefore, the dividing wall column has two side offtakes and methanol is taken off as an intermediate-boiling fraction from one of the side offtakes and the methoxypropanols are taken off as an azeotrope with water as the other intermediate-boiling fraction from the second side offtake.

Distillation columns having side offtakes and a dividing wall, hereinafter also referred to as dividing wall columns, are known. They represent a further development of distillation columns which have only one or more side offtakes but no dividing wall. The use of the last-named type of column is restricted because the products taken off at the side offtakes

are never completely pure. In the case of products taken off at the side offtakes in the enrichment section of the column, which are usually taken off in liquid form, the side product still contains proportions of low-boiling components which should be separated via by the top. In the case of products taken off at side offtakes in the stripping section of the column, which are usually taken off in gaseous form, the side product still contains proportions of high boilers. The use of conventional side offtake columns is therefore restricted to cases in which contaminated side products are permissible.

However, when a dividing wall is installed in such a column, the separation action can be improved. This type of construction makes it possible for side products to be taken off in pure form. A dividing wall is installed in the middle region above and below the feed point and the side offtake. This can be fixed in place by welding or can be merely pushed into place. It seals off the offtake section from the inflow section and prevents crossmixing of liquid and vapor streams over the entire column cross section in this part of the column. This reduces the total number of distillation columns required in the fractionation of multicomponent mixtures whose components have similar boiling points.

This type of column has been used, for example, for the separation of an initial mixture of the components methane, ethane, propane and butane (US 2,471,134), for the separation of a mixture of benzene, toluene and xylene (US 4,230,533) and for the separation of a mixture of n-hexane, n-heptane and n-octane (EP 0 122 367).

Dividing wall columns can also be used successfully for separating mixtures which boil azeotropically (EP 0 133 510).

Finally, dividing wall columns in which chemical reactions can be carried out with simultaneous distillation of the products are also known. Examples which may be mentioned are esterifications, transesterifications, saponifications and acetalizations (EP 0 126 288).

Figure 1 schematically shows the purification of the methanol used as solvent in the synthesis of propylene oxide and of the methoxypropanols by distillation in a dividing wall column having two side offtakes.

Here, the solvent mixture resulting from the preparation of propylene oxide is introduced continuously as feed Z into the dividing column having two side offtakes. In the column, this mixture is separated into a fraction comprising the low boilers L (acetaldehyde, methyl

formate), the two intermediate-boiling fractions M1 (methanol) and M2 (methoxypropanols as an azeotrope with water) and a fraction comprising the high boilers S (water, propylene glycol).

- 5 The low boilers L are taken off at the top of the dividing wall column and the high boilers S are obtained as bottoms.

10 The valuable products M1 and M2 are taken off in liquid or gaseous form from the side offtakes which are located one above the other. For this purpose, it is possible to use receivers in which the liquid or condensing vapor can be collected and which may be located either inside or outside the column.

15 Such a dividing wall column preferably has from 15 to 60, more preferably from 20 to 35, theoretical plates. The process of the present invention can be carried out particularly advantageously using such a design.

In a preferred embodiment of the process of the present invention, therefore, the dividing wall column has from 15 to 60 theoretical plates.

- 20 The upper, combined region of the inflow and offtake part 1 of the column preferably has from 5 to 50%, more preferably from 15 to 30%, of the total number of theoretical plates in the column, the enrichment section 2 of the inflow part preferably has from 5 to 50%, more preferably from 15 to 30%, the stripping section 4 of the inflow part preferably has from 5 to 50%, more preferably from 15 to 30%, the stripping section 3 of the offtake part
25 preferably has from 5 to 50%, more preferably from 15 to 30%, the enrichment section 5 of the offtake part preferably has from 5 to 50%, more preferably from 15 to 30%, the lower combined region 6 of the column preferably has from 5 to 50%, more preferably from 15 to 30%, and the region of thermal coupling 7 preferably has from 5 to 50%, more preferably from 15 to 30%, in each case of the total number of theoretical plates in the column. The
30 dividing wall 8 prevents mixing of liquid and vapor streams.

The sum of the number of theoretical plates in the regions 2 and 4 in the inflow part is preferably from 80 to 110%, more preferably from 90 to 100%, of the sum of the number of theoretical plates in the regions 3, 5 and 7 in the offtake part.

- 35 It is likewise advantageous for the feed point and the side offtakes to be arranged at different heights in the column relative to the position of the theoretical plates. The feed

point is preferably located at a position which is from one to eight, more preferably from three to five, theoretical plates above or below the side offtakes.

The dividing wall column used in the process of the present invention is preferably configured either as a packed column containing random packing or ordered packing or as a tray column. For example, it is possible to use sheet metal or mesh packing having a specific surface area of from 100 to 1000 m²/m³, preferably from about 250 to 750 m²/m³, as ordered packing. Such packing provides a high separation efficiency combined with a low pressure drop per theoretical plate.

In the abovementioned configuration of the column, the region of the column divided by the dividing wall 8, which consists of the enrichment section 2 of the inflow part, the stripping section 3 of the offtake part, the stripping section 4 of the inflow part and the enrichment section 5, or parts thereof is/are preferably provided with ordered packing or random packing and the dividing wall 8 is thermally insulated in these regions.

The solvent mixture to be separated is introduced continuously into the column in the form of the feed stream Z which comprises the low-boiling, intermediate-boiling and high-boiling components. This feed stream is generally liquid. However, it can be advantageous to subject the feed stream to preliminary vaporization and subsequently introduce it into the column as a two-phase, i.e. gaseous and liquid, mixture or in the form of one gaseous stream and one liquid stream. This preliminary vaporization is particularly useful when the feed stream contains relatively large amounts of low boilers. The preliminary vaporization enables a considerable load to be taken off the stripping section of the column.

The feed stream is advantageously metered by means of a pump or via a static inflow height of at least 1 m into the inflow part. This inflow is preferably introduced via a cascade regulation in combination with the regulation of the liquid level in the inflow part. The regulation is set so that the amount of liquid introduced into the enrichment section 2 cannot drop below 30% of the normal value. It has been found that such a procedure is important to even out troublesome fluctuations in the amount or concentration of the feed.

It is likewise important that the division of the liquid flowing down from the stripping section 3 of the offtake part of the column between the side offtake and the enrichment section 5 of the offtake part is set by means of a regulation device so that the amount of liquid going to the region 7 cannot drop below 30% of the normal value.

Adherence to these prerequisites has to be ensured by means of appropriate regulation methods.

Regulation mechanisms for the operation of dividing wall columns have been described, for example, in Chem. Eng. Technol. 10 (1987) 92-98, Chem.-Ing.-Technol. 61 (1989), No. 1, 16-25, Gas Separation and Purification 4 (1990) 109-114, Process Engineering 2 (1993) 33-34, Trans IChemE 72 (1994) Part A 639-644, Chemical Engineering 7 (1997) 72-76. The regulation mechanisms described in this prior art can also be employed for or applied to the process of the present invention.

The regulation principle described below has been found to be particularly useful for the continuously operated purification of the solvent by distillation. It is readily able to cope with fluctuations in loading. The distillate is thus preferably taken off under temperature control.

A temperature regulation device which utilizes the downflow quantity, the reflux ratio or preferably the quantity of runback as regulating parameter is provided in the upper section 1 of the column. The measurement point for the temperature regulation is preferably located from three to eight, more preferably from four to six, theoretical plates below the upper end of the column.

Appropriate setting of the temperature then results in the liquid flowing down from the section 1 of the column being divided at the upper end of the dividing wall so that the ratio of the liquid flowing to the inflow part to that flowing to the offtake part is preferably from 0.1 to 1.0, more preferably from 0.3 to 0.6.

In this method, the downflowing liquid is preferably collected in a receiver which is located in or outside the column and from which the liquid is then fed continuously into the column. This receiver can thus take on the task of a pump reservoir or provide a sufficiently high static column of liquid which makes it possible for the liquid to be passed on further in a regulated manner by means of regulating devices, for example valves. When packed columns are used, the liquid is firstly collected in collectors and from there conveyed to an internal or external receiver.

The vapor stream at the lower end of the dividing wall is set by selection and/or dimensioning of the separation internals and/or incorporation of pressure-reducing devices,

for example orifice plates, so that the ratio of the vapor stream in the inflow part to that in the offtake part is preferably from 0.8 to 1.2, preferably from 0.9 to 1.1.

In the abovementioned regulation principle, a temperature regulation device which utilizes the quantity taken off at the bottom as regulating parameter is provided in the lower combined section 6 of the column. The bottom product can therefore be taken off under temperature control. The measurement point for the temperature regulation device is preferably located from three to six, more preferably from four to six, theoretical plates above the lower end of the column.

In addition, the level regulation in column section 6 (bottom of the column) can be utilized for regulating the quantity taken off at the lower side offtake. For this purpose, the liquid level in the vaporizer is used as regulating parameter. As regulating parameter for the quantity taken off at the upper side offtake, a temperature regulation device is provided in the divided column region 3.

In this arrangement, for example, the fraction comprising the materials of value can be fractionated so that methanol is taken off as intermediate boiler M 1 at the upper side offtake and the methoxypropanols are taken off as an azeotrope with water having a higher boiling point than methanol as intermediate boiler M 2 in still good purity at the lower side offtake.

The differential pressure over the column can also be utilized as regulating parameter for the heating power. The distillation is advantageously carried out at a pressure of from 0.5 to 15 bar, preferably from 5 to 13 bar. The pressure here is measured at the top of the column. Accordingly, the heating power of the vaporizer at the bottom of the column is selected to maintain this pressure range.

This results in a distillation temperature which is preferably in the range from 30 to 140°C, more preferably from 60 to 140°C and in particular from 100 to 130°C. The distillation temperature is measured in the region of the side offtakes.

Accordingly, a preferred embodiment of the process of the present invention provides for the pressure in the distillation to be from 0.5 to 15 bar and the distillation temperature to be from 30 to 140°C.

To be able to operate the dividing wall column in a trouble-free manner, the abovementioned regulation mechanisms are usually employed in combination.

In the separation of multicomponent mixtures into low-boiling, intermediate-boiling and high-boiling fractions, there are usually specifications in respect of the maximum permissible proportion of low boilers and high boilers in the middle fraction. Here, individual components which are critical to the separation problem, referred to as key components, or else the sum of a plurality of key components are/is specified.

Adherence to the specification for the high boilers in the intermediate-boiling fraction is preferably regulated via the division ratio of the liquid at the upper end of the dividing wall. The division ratio is set so that the concentration of key components for the high-boiling fraction in the liquid at the upper end of the dividing wall amounts to from 10 to 80% by weight, preferably from 30 to 50% by weight, of the value which is to be achieved in the streams taken off at the side. The liquid division can then be set so that when the concentration of key components of the high-boiling fraction is higher, more liquid is introduced into the inflow section, and when the concentration of key components is lower, less liquid is introduced into the inflow section.

Accordingly, the specification for the low boilers in the intermediate-boiling fraction is regulated by means of the heating power. Here, the heating power in the vaporizer is set so that the concentration of key components for the low-boiling fraction in the liquid at the lower end of the dividing wall amounts to from 10 to 80% by weight, preferably from 30 to 50% by weight, of the value which is to be achieved in the products taken off at the side. Thus, the heating power is set so that when the concentration of key components of the low-boiling fraction is higher, the heating power is increased, and when the concentration of key components of the low-boiling fraction is lower, the heating power is reduced.

The concentration of low and high boilers in the intermediate-boiling fraction can be determined by customary analytical methods. For example, infrared spectroscopy can be used for detection, with the compounds present in the reaction mixture being identified by means of their characteristic absorptions. These measurements can be carried out in-line directly in the column. However, preference is given to using gas-chromatographic methods. In this case, sampling facilities are then provided at the upper and lower end of the dividing wall. Liquid or gaseous samples can then be taken continuously or at intervals from the column and analyzed to determine their compositions. The appropriate regulation mechanisms can then be activated as a function of the composition.

An object of the process of the present invention is to provide methanol and the methoxypropanols in a purity of preferably at least 95%. The concentration of the key components of the low boilers and of the key components of the high boilers in the solvent should then preferably be below 5% by weight. Low-boiling key components are, for example, acetaldehyde and methyl formate and high-boiling key components are water and propylene glycols.

In a specific embodiment of the dividing wall column, it is also possible for the inflow part and the offtake part which are separated from one another by the dividing wall 8 not to be present in one column but to be physically separate from one another. In this specific embodiment, the dividing wall column can thus comprise at least two physically separate columns which then have to be thermally coupled with one another.

In a preferred embodiment of the process of the present invention, therefore, the dividing wall column is configured as thermally coupled columns.

Such thermally coupled columns generally exchange vapor and liquid between them. However, they can also be operated in such a way that they only exchange liquid. This specific embodiment has the advantage that the thermally coupled columns can also be operated under different pressures, which can make it possible to achieve better setting of the temperature level required for the distillation than in the case of a conventional dividing wall column. In general, it is not necessary for all the columns to be provided with a vaporizer.

These thermally coupled columns are usually operated so that the low-boiling fraction and the high-boiling fraction are taken off from different columns and the operating pressure of the column from which the high-boiling fraction is taken is from 10 to 100 mbar lower than the operating pressure of the column from which the low-boiling fraction is taken.

Furthermore, in the case of coupled columns it can also be advantageous to vaporize bottom streams partly or completely in an additional vaporizer and only then pass them to the next column. This prevaporization is particularly useful when the bottom stream from the first column contains relatively large amounts of intermediate boilers. In this case, the prevaporization can be carried out at a lower temperature level and some of the load is taken from the vaporizer of the second column, if this column is equipped with a vaporizer. This measure also significantly decreases the load on the stripping section of the second column.

The prevaporized stream can be fed to the next column either as a two-phase stream or in the form of two separate streams.

Conversely, it is also possible for gaseous streams taken off at the top to be partly or completely condensed before they are passed to another column. This measure, too, can contribute to better separation of the low-boiling and high-boiling fractions from the two intermediate-boiling fractions and also to better separation of the two intermediate-boiling fractions from one another.

A preferred embodiment of the process of the present invention therefore provides for the liquid bottom stream taken from one of the coupled columns to be partly or completely vaporized before it is fed to the other column and/or the gaseous stream taken from the top of one of the coupled columns to be partly or completely condensed before it is fed to the other column.

Examples of dividing wall columns in the specific embodiment of thermally coupled columns are shown schematically in Figures 2, 3 and 4. These configurations are preferably used when two intermediate boilers are to be separated off from an intermediate-boiling fraction. According to the present invention, the methanol used as solvent in the synthesis of propylene oxide can be separated off as intermediate boiler M 1 in addition to the methoxypropanols (as azeotrope with water) as intermediate boilers M 2 and the low boilers and high boilers L and S.

Figure 2 shows a variant in which three thermally coupled columns are connected in series. Here, the mixture containing the materials of value is fed as feed Z to the first column. Mass transfer generally occurs via vapor d and liquid f. In this way, the low boilers L can be obtained via the top of the first column, methanol M 1 can be obtained from the side offtake of the second column and the methoxypropanols as azeotrope with water M 2 can be obtained from the side offtake of the third column and the high boilers S can be obtained at the bottom. Energy is introduced essentially via the vaporizer V of the last column.

Another possible arrangement is shown in Figure 3. Here, three columns are connected so that the column via which the feed is introduced can at the top exchange vapor d with a further column and can at the bottom exchange liquid f with a third column. M 1 is taken off at the bottom and the low boilers L are taken off at the top of the column connected to the top of the feed column, and M 2 is taken off at the top and high boilers S are taken off at the bottom of the column connected to the bottom of the feed column. It is preferred that only

the columns from which the materials of value are taken have their own energy introduction in the form of the vaporizers V.

Figure 4 shows an arrangement in which a column into which the mixture comprising the materials of value is fed as feed Z is thermally coupled with a dividing wall column. The low boilers L can be separated off at the beginning via the top of the feed column. M 2 is taken off at the side offtake of the dividing wall column, and the lower-boiling product M 1 is taken off at the top of the column. High boilers S are taken off from the dividing wall column as bottoms. Effectively, only the dividing wall column has an energy introduction in the form of the vaporizer V.

In a preferred embodiment of the process of the present invention, therefore, three thermally coupled columns are connected in series and the solvent mixture to be fractionated is fed into the first column from which the low boilers are separated off, the methanol is taken off via the side offtake of the second column and the methoxypropanols as azeotrope with water are taken off via the side offtake of the third column from which the high boilers are taken off as bottoms, or

two columns are each coupled with the column via which the solvent mixture to be fractionated is fed in, with the low boilers being separated off at the top and the methanol being separated off at the bottom of one column and the methoxypropanols as azeotrope with water being separated off at the top and the high boilers being separated off at the bottom of the other column, or

the column via which the solvent mixture to be fractionated is fed in is coupled with a dividing wall column having a side offtake, with the low boilers being separated off via the top of the feed column, the methanol being separated off at the top, the methoxypropanols as azeotrope with water being separated off at the side offtake and the high boilers being separated off at the bottom of the dividing wall column.

The columns of Figures 2 to 4 can also be configured as packed columns containing random packing or ordered packing or as tray columns. For example, sheet metal or mesh packing having a specific surface area of from 100 to 1000 m²/m³, preferably from about 250 to 750 m²/m³, can be used as ordered packing. Such packing provides a high separation efficiency combined with a low pressure drop per theoretical plate.

The solvent mixture to be fractionated in the process of the present invention can be derived from a propylene oxide synthesis using the starting materials known from the prior art.

Propylene can be used as "chemical grade" propylene. Such propylene contains propane, with propylene and propane being present in a volume ratio of from about 97:3 to 95:5.

As hydroperoxide, it is possible to use the known hydroperoxides which are suitable for the reaction of the organic compound. Examples of such hydroperoxides are tert-butyl hydroperoxide and ethylbenzene hydroperoxide. Preference is given to using hydrogen peroxide as hydroperoxide for the oxirane synthesis, with an aqueous hydrogen peroxide solution also being able to be used.

Hydrogen peroxide can be prepared, for example, by the anthraquinone process as described in "Ullmanns Encyclopedia of Industrial Chemistry", 5th Edition, Volume 13, pages 447 to 456.

It is likewise conceivable to obtain hydrogen peroxide by converting sulfuric acid into peroxodisulfuric acid by anodic oxidation with simultaneous evolution of hydrogen at the cathode. Hydrolysis of the peroxodisulfuric acid then leads via peroxomonosulfuric acid to hydrogen peroxide and sulfuric acid, which is thus recovered.

It is of course also possible to prepare hydrogen peroxide from the elements.

The methanol used as solvent for the reaction can be used in the form of customary technical-grade product. It preferably has a purity of at least 95% and a water content of not more than 5% by weight.

As catalysts for the preparation of propylene oxide, preference is given to using catalysts which comprise a porous oxidic material, e.g. a zeolite. The catalysts used preferably comprise a titanium-, germanium-, tellurium-, vanadium-, chromium-, niobium- or zirconium-containing zeolite as porous oxidic material.

Specific mention may be made of titanium-, germanium-, tellurium-, vanadium-, chromium-, niobium- and zirconium-containing zeolites having a pentasil zeolite structure, in particular the types which can be assigned X-ray-crystallographically to the ABW, ACO, AEI, AEL, AEN, AET, AFG, AGI, AFN, AFO, AFR, AFS, AFT, AFX, AFY, AHT, ANA, BIK, BOG, BPH, BRE, CAN, CAS, CFI, CGF, CGS, CHA, CHI, CLO, CON, CZP, DAC, DDR, DFO,

DFT, DOH, DON, EAB, EDI, EMT, EPI, ERI, ESV, EUO, FAU, FER, GIS, GME, GOO, HEU, IFR, ISV, ITE, JBW, KFI, LAU, LEV, LIO, LOS, LOV, LTA, LTL, LTN, MAZ, MEI, MEL, MEP, MER, MFI, MFS, MON, MOR, MSO, MTF, MTN, MTT, MTW, MWW, NAT, NES, NON, OFF, OSI, PAR, PAU, PHI, RHO, RON, RSN, RTE, RTH, RUT, SAO, SAT, SBE, SBS, SBT, SFF, SGT, SOD, STF, STI, STT, TER, THO, TON, TSC, VET, VFI, VNI, VSV, WIE, WEN, YUG, ZON structure or to mixed structures comprising two or more of the abovementioned structures. Furthermore, titanium-containing zeolites having the ITQ-4, SSZ-24, TTM-1, UTD-1, CIT-1 or CIT-5 structure are also conceivable for use in the process of the present invention. Further titanium-containing zeolites which may be mentioned are those of the ZSM-48 or ZSM-12 structure.

Particular preference is given to Ti zeolites having an MFI or MEL structure or an MFI/MEL mixed structure. Very particular preference is given to the titanium-containing zeolite catalysts which are generally referred to as "TS-1", "TS-2", "TS-3" and also Ti zeolites having a framework structure isomorphous with β -zeolite.

It is especially advantageous to use a heterogeneous catalyst comprising the titanium-containing silicalite TS-1.

It is possible to use the porous oxidic material itself as catalyst. However, it is of course also possible for the catalyst used to be a shaped body comprising the porous oxidic material. All processes known from the prior art can be used for producing the shaped body from the porous oxidic material.

Noble metals in the form of suitable noble metal components, for example in the form of water-soluble salts, can be applied to the catalyst material before, during or after the one or more shaping steps in these processes. This method is preferably employed for producing oxidation catalysts based on titanium silicates or vanadium silicates having a zeolite structure, and it is thus possible to obtain catalysts which contain from 0.01 to 30% by weight of one or more noble metals from the group consisting of ruthenium, rhodium, palladium, osmium, iridium, platinum, rhenium, gold and silver in this way. Such catalysts are described, for example, in DE-A 196 23 609.6.

Of course, the shaped bodies can be processed further. All methods of comminution are conceivable, for example splitting or crushing the shaped bodies, as are further chemical treatments as are described above by way of example.

When a shaped body or a plurality thereof is used as catalyst, it/they can, after deactivation has occurred in the process of the present invention, be regenerated by a method in which the deposits responsible for deactivation are burned off in a targeted manner. This is preferably carried out in an inert gas atmosphere containing precisely defined amounts of oxygen-donating substances. This regeneration process is described in DE-A 197 23 949.8. It is also possible to use the regeneration processes mentioned there in the discussion of the prior art.

In general, the reaction temperature for the preparation of the propylene oxide in steps (i) and (iii) is in the range from 0 to 120°C, preferably in the range from 10 to 100°C and more preferably in the range from 20 to 90°C. The pressures which occur range from 1 to 100 bar, preferably from 1 to 40 bar, more preferably from 1 to 30 bar. Preference is given to employing pressures under which no gas phase is present.

The concentration of propylene and hydrogen peroxide in the feed stream is generally selected so that the molar ratio is preferably in the range from 0.7 to 20, more preferably in the range from 0.8 to 5.0, particularly preferably in the range from 0.9 to 2.0 and in particular in the range from 1.0 to 1.6.

The residence times in the reactor or reactors in the propylene oxide synthesis depend essentially on the desired conversions. In general, they are less than 5 hours, preferably less than 3 hours, more preferably less than 1 hour and particularly preferably about half an hour.

As reactors for the propylene oxide synthesis, it is of course possible to use all conceivable reactors which are best suited to the respective reactions. A reactor is not restricted to an individual vessel. Rather, it is also possible to use, for example, a cascade of stirred vessels.

Fixed-bed reactors are preferably used as reactors for the propylene oxide synthesis. Further preference is given to using fixed-bed tube reactors as fixed-bed reactors.

In the above-described propylene oxide synthesis which is preferably employed, particular preference is given to using an isothermal fixed-bed reactor as reactor for step (i) and an adiabatic fixed-bed reactor for step (iii), with the hydroperoxide being separated off in a separation apparatus in step (ii).

The invention is illustrated by the following example.

Example

Propylene oxide was prepared from propylene by reaction with hydrogen peroxide using the method described in WO 00/07965, with the reaction being carried out in methanol as solvent. The solvent mixture comprising methanol and the methoxypropanols which was obtained after the propylene oxide had been separated off and was to be worked up had the following composition:

about 0.2% by weight of low boilers comprising the key components acetaldehyde, methyl formate,
about 79.8% by weight of methanol and about 5.0% by weight of methoxypropanols as intermediate boilers, and
about 15.0% by weight of high boilers including the key components water and 1,2-propylene glycol.

The objective was to limit the sum of the impurities in the methanol purified by distillation to not more than 5% by weight and to isolate the methoxypropanols in the azeotrope with water in very high purity. For this purpose, the mixture was distilled with the aid of a dividing wall column having two side offtakes, with methanol being taken off from the upper side offtake of the column and the methoxypropanols being taken off as an azeotrope with water from the lower side offtake and the low boilers being taken off at the top and the high boilers at the bottom of the column. The heating power of the bottom vaporizer was set so that the sum of the concentrations of the key components in the material taken off at the upper side offtake was less than 5% by weight.

The energy required in the distillation was used as a measure of the effectiveness of the separation. It was calculated as the vaporizer power divided by the throughput per unit time through the column. As column arrangements, the configurations shown in the table were selected:

Column arrangement	Energy requirement/(kg/h) [kW/(kg/h)]	Energy saving [%]
Three conventional columns connected in series	1.01	-
Dividing wall column	0.81	20

It can clearly be seen that the dividing wall arrangement had a considerable energy advantage compared to the conventional distillation apparatus, since the energy required for the distillation was significantly lower than in the case of the distillation using three
5 conventional columns connected in series.

The methanol obtained by distillation in the dividing wall column could be reused for the propylene oxide synthesis.

List of reference numerals for Figures 1 to 4:

	1	Combined region of the inflow and offtake part of the dividing wall column
	2	Enrichment section of the inflow part
5	3	Stripping section of the offtake part
	4	Stripping section of the inflow part
	5	Enrichment section of the offtake part
	6	Combined region of the inflow and offtake part
	7	Region of thermal coupling
10	8	Dividing wall
	Z	Feed
	L	Low boilers
	M1	Intermediate boilers (methanol)
15	M2	Intermediate boilers (1-methoxy-2-propanol and 2-methoxy-1-propanol as azeotrope with water)
	S	High boilers
	K	Condenser
	V	Vaporizer
20	d	Vapor
	f	Liquid

Horizontal and diagonal or indicated diagonal lines in the columns symbolize packing made up of random packing elements or ordered packing which may be present in the column.